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CASE POSTALE 6128, SUCCURSALE A, MONTRÉAL, QUÉBEC, H3C 3J7

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NETPLAN: A NETWORK OPTIMIZATION MODEL FOR TACTICAL PLANNING IN THE LESS-THAN-TRUCKLOAD MOTOR-CARRIER INDUSTRY

by

Jacques Roy*
and
Louis Delorme**

* Département des Sciences administratives, Université du Québec à Montréal.

** Centre de recherche sur les transports, Université de Montréal.

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ABSTRACT

This paper reports on the use of a network optimization model for assisting motor-carriers in the analysis of various operating strategies and network configurations by globally considering the design of the service network of the company and the routing of freight through this network under the double criteria of economic efficiency and service quality. The methodological aspect of the approach is presented, along with experimental results obtained from various scenario analyses at two large motor-carriers.

Key words : intercity freight transportation, trucking industry, tactical planning, network optimization model.

RÉSUMÉ

Nous présentons, dans cet article, les grandes lignes d'une étude portant sur l'expérimentation d'un modèle d'optimisation dans l'industrie du transport routier des marchandises. Ce modèle permet d'analyser de nombreuses stratégies d'opération en traitant à la fois le problème du design du réseau de services de transport de l'entreprise et celui de l'acheminement des marchandises. Les critères de décision tiennent compte des facteurs économiques et de la qualité du service. Nous décrivons brièvement l'aspect méthodologique de notre approche et nous présentons plusieurs résultats tirés d'études expérimentales réalisées chez deux grandes entreprises de camionnage.

Mots-clés : transport interurbain des marchandises, industrie du camionnage, planification tactique, modèle d'optimisation de réseau.

1. INTRODUCTION

The current deregulation trend of the North American transportation industry places the intercity freight motor-carrier in a highly competitive environment where only rapid and precise adjustments of prices and services to external factors allow it to survive and prosper. Consequently, a most valuable asset for the company is the capability to efficiently generate good operating strategies aimed at satisfying not only the traditional cost minimization but also the somewhat conflicting service quality criteria.

We have developed a network optimization model aimed at assisting motor-carriers attain these objectives. It integrates the many facets of the decision-making process at the tactical (i.e. mid-term) level of planning, such as the design of the transportation service network and the routing of freight; it describes their relationships and network-wide influence.

We present in this paper results taken from experimental studies conducted at two large Canadian carriers. Our objective is to bring out the good behaviour of our model as well as the quality of its solutions. We first give an outline of how motor-carriers actually operate. We then describe the problem and review briefly existing planning models that can be used at the tactical decision level. The next section covers the methodological aspect of our approach. It is followed by a short discussion on results obtained from various scenario analyses. Finally, we conclude with an overview of the new developments involving our model, along with other related problems which are currently under study.

2. MOTOR-CARRIERS OPERATIONS

Intercity trucking companies are generally specialized in the transportation of one of the following type of shipments:

1) truckload or TL freight;

2) less-than-truckload or LTL freight;

3) parcels. (Roy, 1984)

TL freight is characterized by individual shipments which require an entire trailer - i.e. one per shipment. This freight does not require sorting and handling as it moves directly from shipper to consignee. As a result, investment in terminals and in specialized city pickup and delivery equipment is not necessary in this case (Barker, Sharon and Sen, 1981).

An LTL carrier typically hauls shipments in the range of 100 to 10,000 pounds - 50 to 4500 kg (Powell and Sheffi, 1983); it also often provides TL services. Since a trailer can hold 30,000 to 50,000 pounds depending on the density of freight, it is necessary for the carrier to consolidate many shipments to make economic use of the vehicle. This requires the establishment of a large number of terminals to sort freight. These terminals might be either end-of-line terminals, which correspond to points of origin and destination of freight, breakbulk terminals which perform exclusively consolidation of freight, or a combination of these two (in the United States, most trucking companies make a distinction between end-of-line terminals and breakbulk terminals — see for instance Powell and Sheffi (1983) — which is not always the case in Canada). End-of-line terminals have to maintain a fleet of small trucks for handling pickups and deliveries in the city.

For a better understanding of a LTL carrier's operations, Figure 1 represents the typical flow of shipments (Wyckoff, 1974). The cycle starts with a pickup demand which is seldom known in advance and may vary significantly from one day to another. Demand for transportation services also varies according to seasonal variations and type of traffic. For example, early spring and fall are peak periods in the garment industry. Shipments

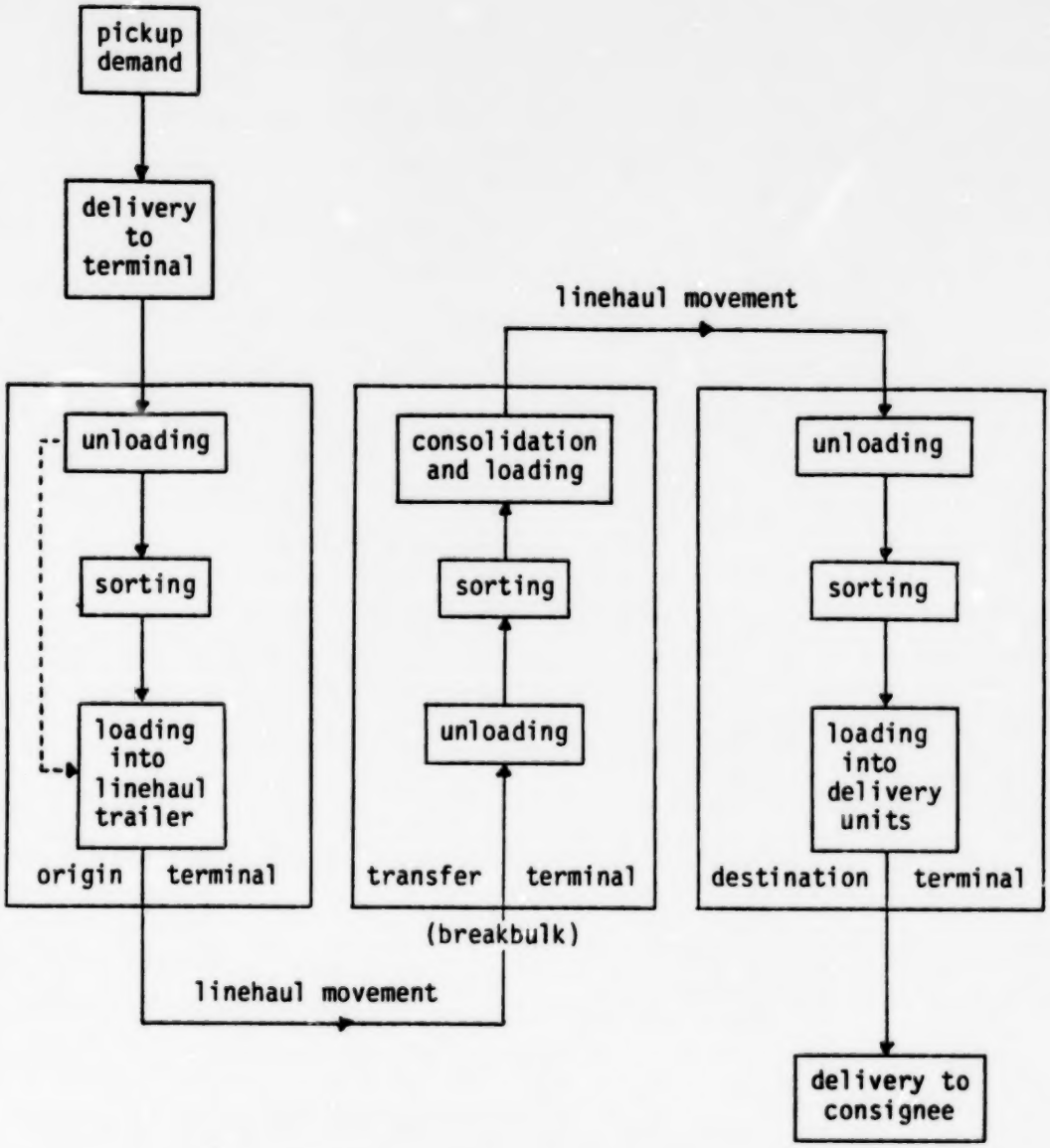


Figure 1. Typical flow of LTL shipments (Roy and Picard, 1984).

are generally collected in the afternoon and then delivered to the origin terminal. Freight is then loaded into a linehaul trailer and moved to the nearest breakbulk terminal if the origin terminal does not perform the sortation function. Otherwise, freight is sorted according to its destination and then moved to its loading area where it awaits loading into

linehaul trailers. Traffic addressed to other points in the origin city is directed to loading zones for local delivery (normally the next morning). As mentioned earlier, it is not always possible to economically dispatch a trailer for each destination where traffic is addressed. Freight is then consolidated into trailers for an intermediate terminal (i.e. a breakbulk terminal) where it will be loaded with other traffic for movement to its final destination. In the worst case, traffic will once again be unloaded, sorted and reloaded at the transfer terminal. However, it is sometimes possible to keep this traffic in the "nose" of the trailer and add some more traffic to it, in which case the handling costs are considerably reduced. At the destination terminal, traffic will once again be unloaded, sorted and moved to a loading area for local delivery to its consignee. Note that linehaul movements occur mostly during the night, so that freight can be delivered to consignees in the morning (Roy and Picard, 1984; Roy, 1984).

Carriers specialized in the transportation of parcels - small shipments of less than 50 pounds, such as UPS in the United States and Canada Post Corporation, share many points in common with an LTL carrier. More particularly, they must also consolidate shipments; their terminal network is thus in some ways very similar to an LTL carrier's one. Note however that the sortation process is much more demanding than in the LTL case.

3. THE LOAD PLANNING PROBLEM

One of the main mid term problems facing LTL carriers is without any doubt the determination of the transportation - or load - plan for the next coming months. Powell (1986) defines this problem as the specification of how freight should be routed (and consolidated) over the network, given a set of direct services between terminals. This routing is done by minimizing transportation and handling costs while improving - or at least

maintaining - preset levels of service. A load plan must consider the three following interrelated subproblems:

1) the service network design, i.e. the selection of routes on which carrier services will be offered and the determination of the characteristics of each service such as its mode, speed and frequency (number of vehicle departures on a given route per planning period);

2) the traffic distribution, i.e. for each origin-destination pair (or traffic class) with a positive traffic demand, which sequence of services will be used to move freight and which terminals it will pass through;

3) the empty vehicle movements, i.e. the determination of empty movements required to establish the balance between the number of vehicles departing and those arriving at each originating terminal in the network.

The working out of a good load plan is a complex task, as illustrated in the following example. Let us suppose that the demand for LTL transportation for a given origin-destination pair is expected to increase in the coming months. We then could increase the number of trailer departures at the origin terminal, and possibly at the intermediate terminals, in order to satisfy this additional demand; such a policy would increase transportation costs while maintaining present service speed and reliability levels. We could also decide to maintain the existing number of movements, and forward the additional freight through other intermediate terminals in order to maximize the utilization of trailer equipment. However, this second policy would increase freight handling costs, total transit time and terminal congestion which, in turn, could affect service reliability. Thus, the strategies developed for one problem interact with those established for other problems. Therefore, decisions should be made globally, network-wide, in an integrated manner (Crainic and Roy, 1987).

4. EXISTING PLANNING MODELS: A BRIEF OVERVIEW

One of the first attempts to model the load planning problem is the development of a "network operations evaluator" by Terziev, Richardson and Roberts (1978). This evaluator is a supply model which takes into account all the activities of a carrier, from pickup of shipments to their delivery, including freight handling at breakbulk facilities and intercity movements. It was designed to help planners with the evaluation of global operating strategies by estimating their impact on operation costs and level of service (i.e. service rapidity and reliability). It appears however that this evaluator has never been tested with actual data.

The same type of modeling approach has been adopted by Barker, Sharon and Sen (1981) for a large American motor-carrier, ANR Freight Systems Inc. Their model can be used in interactive mode and, as the previous one, measures the outcome of alternative operating plans in terms of costs and level of service. Given the load plan currently in use, the model first consolidates all shipments passing through breakbulk terminals in order to determine the frequency of each service. It then determines for each terminal the number of trucks required to balance the network through linear programming. Finally, it proposes (if possible) for each traffic class an alternative route (less costly or with higher service standards). The overall system has proved to be highly profitable to ANR Freight Systems Inc., as indicated by some figures on its utilization reported by the authors.

The main characteristic of the two above-mentioned models is their descriptive nature. Although they allow planners to evaluate their transportation strategies in measuring the trade-offs between operating costs and service quality, these models offer poor assistance in the determination of an optimal transportation plan (Delorme, Roy, and Rousseau, 1987).

A global optimization modeling approach is, in our opinion, more appropriate for the load planning problem. Powell and Sheffi (1983) agree with our view, as they have proposed a network optimization model to solve the problem. Their model was later extended and the solution method improved (Powell, 1986) in order to be installed as a computer interactive package at a large LTL firm, Ryder/PIE Nationwide (Powell and Sheffi, 1986). The formulation yields a large mixed integer programming problem which takes into account the design of the service network as well as the traffic routing and the empty balancing process. The optimal load plan is obtained by minimizing the total linehaul and handling cost while ensuring that satisfactory levels of service are provided. The solution algorithm is based on a local improvement heuristic which drops and adds links (i.e. services) to a given initial network using a specific sequencing logic. After each modification, flow is rerouted using a decomposition method and an adaptation of a shortest path algorithm. Numerical experiments carried out by Powell (1986) on a network composed of 12 breakbulk and 128 end-of-line terminals suggest that the solution method works efficiently. One of the main features of the system is its capability to deal with unprogrammable decision rules regarding the service network design: the planner may decide in an interactive manner where direct services should be offered, given suggestions provided by the model.

Despite the apparent success of their model for solving the load planning problem, several aspects of intercity freight transportation systems were not considered by Powell and Sheffi. In particular, service frequencies are not explicit decision variables in the model; they are more an output of it as they are estimated from the total flow (in trailer-loads) carried on each link of the service network. Moreover, the variable flows are not restricted to take on integer values only. In addition, the model ignores congestion phenomena which happen at breakbulk terminals when

for instance the volume to classify or the number of trucks to unload increase. Finally, service characteristics such as transit time of freight and its variability are not considered in the model.

According to the authors, these simplications were made necessary because of the size and the nature of the problem. Indeed, national carriers in the U.S.A. typically operate a network of 300 or more terminals including those dedicated only to breakbulk functions.

Recently, Crainic and Rousseau (1985) have proposed a general modeling framework for the medium-term planning problem of multimode, multicommodity freight transportation systems which takes into account the above-mentioned elements missing from Powell and Sheffi's model. It was first used to solve a complex rail application (Crainic, Ferland and Rousseau, 1984) and later adapted by Roy (1984) for LTL problems. An overview of the methodology as well as the general design of the planning tool currently under development are presented in a paper by Crainic and Roy (1987) The structure of Roy's model, named NETPLAN ("NETwork PLANning") is presented in the next section.

Note that other valuable studies have been conducted on service network design and freight routing problems for LTL carriers, as pointed out in Delorme, Roy, and Rousseau's paper (1987) which reviews planning models in the trucking industry.

5. THE MODEL

NETPLAN is intended to assist motor-carriers in their decision-making process concerning the design of the service network, the routing of freight and the empty vehicles balancing problem. It is formulated as a non-linear mixed integer programming problem, where service frequencies as well as the volume of freight moving on each route (or itinerary) through the network are the main decision variables. Their values are determined by minimizing a total system cost (defined below) while satisfying the

demand for transportation, specified for each origin-destination pair (or traffic class), and integrality constraints on frequencies; note also that the decision variables are required to be nonnegative. The trade-offs to be made between operating costs and both speed and reliability of service are explicitly considered by NETPLAN at the objective function level. Thus, the main function of NETPLAN is to propose a solution that could provide the best service at minimum cost.

The total system cost is the sum of:

1) the intercity transportation costs, which may vary according to the type of services used and their frequencies;

2) the freight consolidation costs, which depend on the amount of freight handled at breakbulk terminals;

3) the capacity penalty costs, which penalize the over-utilization of trailer capacity for each transportation service;

4) the service penalty costs, which are incurred when service performance standards are not met, considering both the mean and variance of planned transit times for each traffic class.

Service penalty costs are modeled by paying attention to the estimation of delays occurring at terminals and over the road. These delays fall into one of the following four categories:

1) the intercity transportation time for each service. It is usually estimated from historical data;

2) the waiting time of vehicles at each terminal before their unloading. This delay depends on the size and configuration of the terminal as well as on the productivity of the employees assigned to handling operations. Its estimation is based on queuing theory;

3) the time incurred to unload and classify freight at each terminal. It is expressed as a function of the average volume of freight carried by a vehicle (determined by NETPLAN) and of the unloading rate at the terminal in volume units per hour;

4) the frequency delay for each service, i.e. the time spent by freight at loading docks waiting for the next vehicle departure. This delay, which is obtained from queuing analysis methods, depends on the service capacity as well as on its utilization rate.

The transit time for a given itinerary is computed by summing frequency delays and transportation times related to each service used, as well as all delays incurred at each terminal encountered. For a more detailed description of all these terms, see the work by Roy (1984).

The modeling structure of NETPLAN is as follows:

$$\underset{(F,X)}{\text{Minimize}} \Big\{ \sum_{\ell} C_{\ell}^{t} F_{\ell} \qquad \text{(transportation costs)}$$

$$+ \sum_{j} C_{j}^{c} X_{j}^{c} \qquad \text{(freight consolidation costs)}$$

$$+ \sum_{\ell} C_{\ell}^{p} \{\min[0,\ 0.9 - X_{\ell}/\alpha_{\ell} F_{\ell}]\}^{2} \qquad \text{(capacity penalty costs)}$$

$$+ \sum_{m} \sum_{k} C_{m}^{s} X_{k}^{m} \{\min[0, S_{m} - E(T_{k}^{m}) - n\sigma(T_{k}^{m})]\}^{2} \Big\} \qquad \text{(service penalty costs)}$$

subject to

$$\begin{cases} \sum_{k} X_{k}^{m} = d^{m} & \text{for all } m \qquad \text{(demand constraints)} \\ X_{k}^{m} > 0 & \text{for all } m \text{ and } k \\ 0 \leq F_{\ell} \leq E_{\ell} \text{ and } F_{\ell} \text{ integer} & \text{for all } \ell \end{cases}$$

where decision variables are:

F_ℓ , the frequency of service ℓ,

and X^c_j, X_ℓ, and X^m_k, the volumes of freight handled at terminal j, moved by service ℓ, and routed through the k^{th} itinerary for traffic class m respectively,

and where:

C^t_ℓ is the transportation unit cost for service ℓ,

C^c_j the consolidation unit cost at terminal j,

C^p_ℓ the capacity penalty unit cost for service ℓ (usually set to C^t_ℓ),

α_ℓ the average capacity of vehicles assigned to service ℓ,

C^s_m the service penalty unit cost for traffic class m,

S_m the required service standard time for traffic class m,

T^m_k the transit time of freight moving on the k^{th} itinerary of traffic class m (it depends both on the X and the F variables),

$E(T^m_k)$ the average transit time and $\sigma(T^m_k)$ its standard deviation,

n a positive number which depends on the required service reliability,

d^m the demand for traffic class m,

and E_ℓ an upper bound on the frequency of service ℓ.

Other types of constraints may be easily added to the model through the use of penalty costs at the objective function level, such as restrictions on the utilization of given types of vehicles. NETPLAN can also take into account other specific operations of LTL carriers, as for instance the transportation of baseloads when the LTL volume on a given link of the service network is insufficient to justify the regular use of vehicles in

order to maintain high service standards (a baseload is a shipment which takes up about half a trailer capacity. It remains always in the "nose" of the trailer — the unused space may be filled up with LTL shipments — and it is considered as a TL shipment; it is therefore never handled at terminals). Note finally that the model may be extended to handle several types of products for the planning of the activities of carriers specialized in the transportation of parcels. All these modeling characteristics are treated in a paper by Delorme and Roy (1988).

One of the main characteristics of NETPLAN's formulation is its large size. To solve such a problem, Crainic (1982) has developed an algorithm based on a decomposition scheme, which makes use of its particular structure. The solution method works alternatively on the following two subproblems:

1) Service network design: given a fixed traffic distribution, frequencies are modified, one at a time, to improve the objective. If this is not possible, the algorithm stops. Finite differences are used to determine which frequencies have to be changed.

2) Traffic routing and distribution: given service frequencies, the optimal traffic distribution is determined by a decomposition procedure which considers cyclically each traffic class, while all others are kept fixed. For each subproblem, a new itinerary is first generated by a shortest path algorithm; marginal costs are used to measure the "lenght" of an itinerary. Then, the traffic distribution is reoptimized using a modified steepest descent technique.

The algorithm is described in more details and its performance analyzed in a paper by Crainic and Rousseau (1985).

After the above problem has been solved, the balance between the number of trucks leaving and those arriving at each terminal in the network must be re-established. This is done by a procedure developed by Roy (1984) which calls for the addition or the elimination of frequencies required to solve the imbalance while minimizing total costs. The procedure is based on a modified version of the transportation simplex method. It is flexible enough to take into account the possibility of soliciting returns loads (i.e. TL shipments) and adjust the imbalance forecast accordingly.

6. EXPERIMENTAL RESULTS

NETPLAN's performance was tested on actual data provided by two LTL trucking companies: CN Express (CNX) in October 1982 and Transport Brazeau Inc. in March 1985. CNX, a division of Canadian National, was then operating a network of 34 terminals, serving a total of 959 origin-destination pairs (traffic classes) all across Canada with some 289 different services. These transportation services varied according to their O-D pair, equipment ownership and capacity, mode (tractor-trailer, piggyback, container or boxcar) and responsibility for returning the equipment to its origin.

Transport Brazeau Inc. was also a national carrier operating 35 terminals and serving 453 traffic classes from Vancouver to Quebec City with some 259 transportation services but its operations were largely concentrated in the province of Quebec, thus providing us with an opportunity to test NETPLAN on a different network configuration.

6.1 The CNX experiment

The problem was solved on a CDC Cyber 173 computer in approximately 540 sec. CPU. This result is quite satisfactory considering the size and complexity of the problem and the planning decision level. This solution time was achieved by taking advantage of the unequal distribution of the traffic among O-D pairs. Indeed, we observed that the 288 most important

traffic classes, i.e. 30% of all traffic classes, represented almost 92% of all freight demand. Since 80% of computer time is spent solving the subproblem of optimally distributing freight among itineraries for all traffic classes, the solution time was reduced by working alternatively on all traffic classes and on those 30% most important ones.

Table 1 compares results obtained by CNX in October 1982 with those obtained when using NETPLAN according to three different cases:

Case #1: Actual company's performance as measured by CNX's information system in October 1982.

Case #2: Transportation services frequencies are set at the levels observed in October 1982 and NETPLAN is used only to distribute freight among itineraries in order to minimize total costs.

Case #3: The problem is solved entirely using NETPLAN, i.e. for both service network design and traffic routing subproblems, with actual demand data from October 1982.

These results indicate that NETPLAN could be used to significantly increase the number of traffic classes provided with a reliable service while slightly reducing total operating costs. It is fair to say however that CNX was desperately trying to reduce its operating costs during that period and its rather poor service performance was due to a lack of sufficient transportation capacity which resulted in freight being left behind at loading docks. Furthermore, it is not quite fair to compare results obtained in cases #2 and #3 without taking into account the equipment imbalance generated by each solution. Therefore, the network equipment balance was re-established for both case #2 and case #3 and results are shown in Table 2.

These results suggest that the solution obtained when service frequencies are set by CNX (case #2) generates very little equipment imbalance compared to the solution proposed by NETPLAN (case #3). Nevertheless,

Table 1.

Company performance vs model results

Performance criteria	CNX (Case #1)	NETPLAN (CNX frequencies) (Case #2)	NETPLAN (Case #3)
A) Weekly costs			
• transportation	$548,623	$548,623	$480,323
• freight handling	46,256	107,198	65,353
SUB-TOTAL	$594,879	$655,821	$545,676
• capacity penalty	N/A	$171,436	$ 82
• service penalty	N/A	576,387	102,138
TOTAL	N/A	$1,403,644	$647,896
B) Percentage of traffic classes provided with a reliable service			
• major traffic classes	20%	56%	76%
• all traffic classes	N/A	45%	71%
C) Other statistics			
• frequencies used	1,412	1,412	1,276
• itineraries used	N/A	2,722	1,832

Table 2.

Results obtained before and after establishing equipment balance

Performance criteria	Network unbalanced		Network balanced	
	Case #2 (F_ℓ set by CNX)	Case #3 (F_ℓ set by NETPLAN)	Case #2	Case #3
A) Weekly costs				
• transportation	$548,623	$480,323	$590,716	$596,904
• freight handling	107,198	65,353	107,198	66,360
SUB-TOTAL	$655,821	$545,676	$697,914	$663,264
• capacity penalty	$171,436	$ 82	"$120,693"	"$493"
• service penalty	576,387	102,138	"488,566"	"99,419"
TOTAL	$1,403,644	$647,896	$1,307,174	$763,176
B) Service performance				
• major traffic classes	56%	76%	56%	76%
• all traffic classes	45%	71%	45%	71%
C) Other statistics				
• frequencies used	1,412	1,276	1,506	1,442
• itineraries used	2,722	1,832	2,722	2,272

through better routing, NETPLAN proposes a balanced network solution that provides sufficient capacity to significantly improve service performance while maintaining operating costs at a minimum. It should be noted here that intangible service and capacity penalty costs will only be modified if the additional services required to re-establish the equipment balance are added before the actual planning period. This is why those penalty costs are expressed between quotation marks in Table 2.

6.2 Further analyses using data from CNX and Brazeau

Various sensitivity and scenario analyses were performed on the two sets of data provided by CNX and Transport Brazeau Inc. Of particular interest are the studies conducted on the relation between operating costs and service performance and the sensitivity analyses performed with respect to demand variations.

6.2.1 Cost/service trade-offs

Table 3 shows the results obtained when varying the service penalty unit cost C_m^s from zero to its original value $\bar{C}_m^s$ on the set of data provided by CNX. When the service penalty unit cost is set to zero, a minimum cost solution is obtained providing a "lower bound" on operating costs. This solution still provides 35% of all traffic classes with an acceptable service performance in terms of both speed and reliability. As the service penalty unit cost is increased to 1/8 of its original value, service performance increases drastically to a level where 60% of all traffic classes are satisfied. Service performance then slowly increases at the expense of operating costs each time C_m^s is doubled. This cost/service relationship is better illustrated in figure 2.

Table 3.

Results obtained when varying the service penalty unit cost C_m^s on CNX data

Performance criteria	$C_m^s = 0$	$C_m^s = 1/8\ C_m^s$	$C_m^s = \frac{1}{4}C_m^s$	$C_m^s = \frac{1}{2}C_m^s$	$C_m^s = C_m^s$
A) Weekly costs					
• transportation	$426,191	$448,293	$454,144	$475,027	$480,323
• freight handling	62,440	63,800	64,575	64,989	65,353
SUB-TOTAL	$488,631	$512,093	$518,719	$540,016	$545,676
• capacity penalty	$ 375	$ 63	$ 165	$ 204	$ 82
• service penalty	0	32,746	52,229	71,039	102,138
TOTAL	$489,006	$544,902	$571,113	$611,259	$647,896
B) Service performance					
(all traffic classes)	35%	60%	63%	69%	71%
C) Frequencies used					
	942	1,063	1,094	1,174	1,276

When examining figure 2, one could question the feasibility of providing 100% of all traffic classes with acceptable service standards. In fact, we discovered that service targets were simply impossible to achieve for 56 O-D pairs (5,8% of all traffic classes) because they were arbitrarily set much too high (a not so uncommon practice in the industry!).

The same type of analyses was also performed on the set of data provided by Transport Brazeau Inc. The results are expressed in figure 3. Actual company performance is illustrated by the point "B" on the graph. It is clear again that substantial savings in operating costs and improvements in service performance could be potentially achieved by using the transportation services and itineraries proposed by NETPLAN. We also note that a minimum cost solution (where $C_m^s = 0$) would not provide any O-D pair with acceptable service levels, contrary to what was observed in the CNX experimentation.

Figures 2 and 3 clearly demonstrate one of the advantages of using NETPLAN as a tool for performing important analyses such as the study of cost/service trade-offs, an essential and crucial management task in the motor-carrier industry (Roy and Picard, 1984).

6.2.2 Demand variations

The demand level, d_m, was varied by ±20% for all traffic classes m. Results are reported in table 4 for the CNX experimentation and in table 5 for data provided by Transport Brazeau Inc. This kind of analysis is interesting because it is one of NETPLAN's most important features to be used as a tactical planning tool when seasonal demand variations are expected.

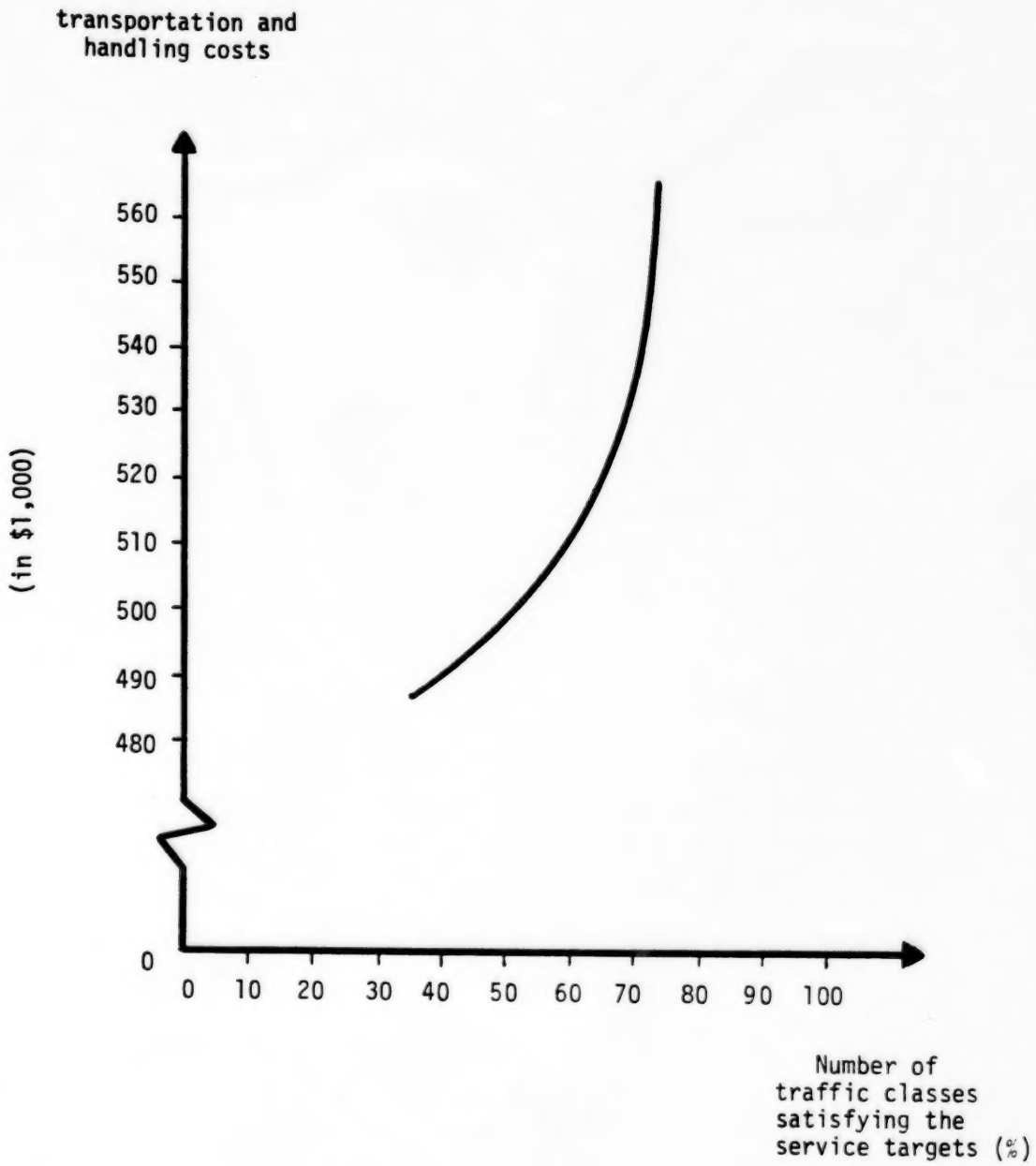
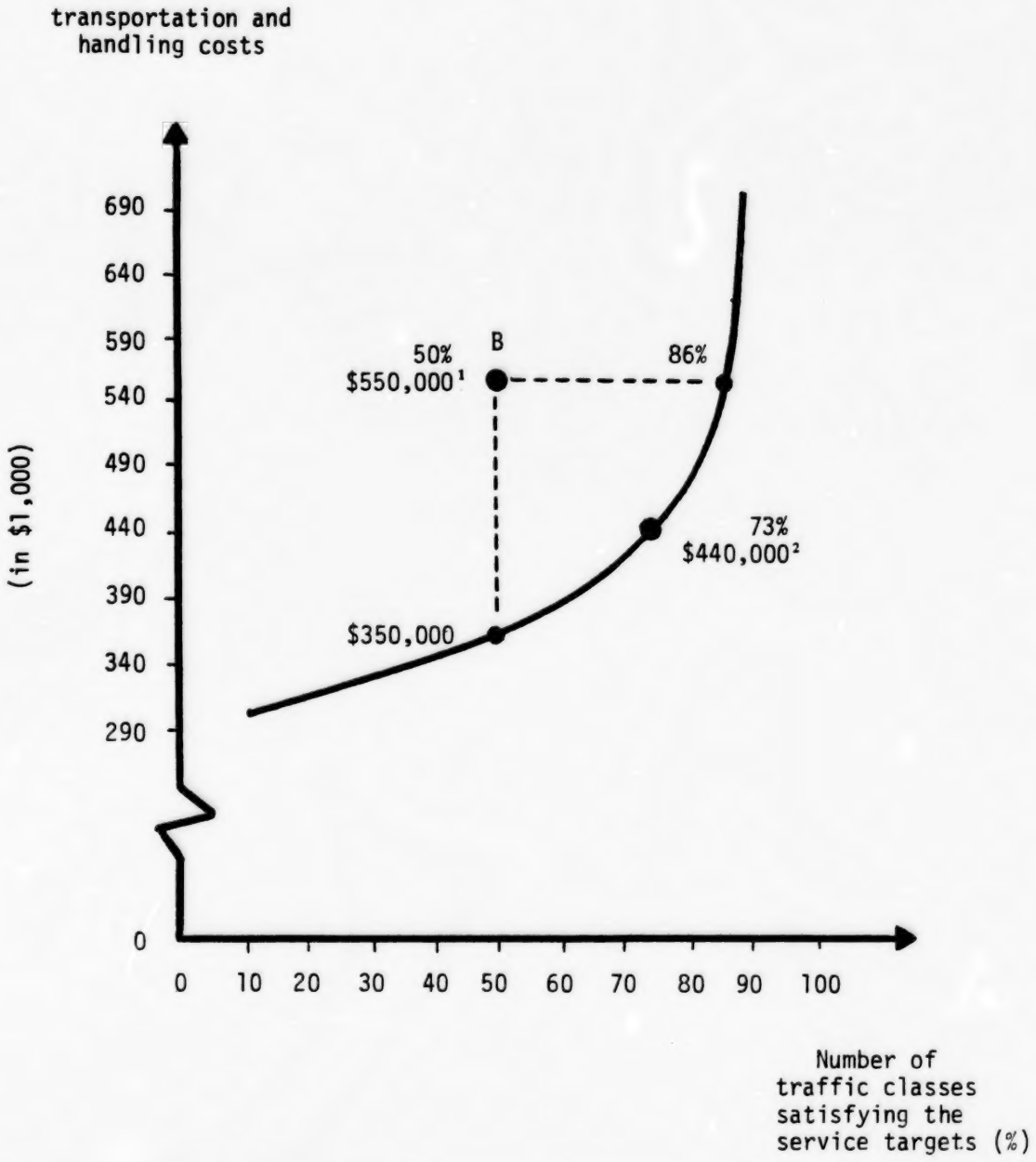


Figure 2. Cost/service trade-offs using CNX data



[1] actual company performance (approximate figures)
[2] one of NETPLAN's solutions

Figure 3. Cost/service trade-offs using data from Transport Brazeau Inc.

When examining the results presented in tables 4 and 5, we note that variations in total operating cost are not as important as those applied to demand data. This is due to the relative importance of transportation cost which vary according to the service frequencies used. Service frequencies will not vary linearly with demand as unused capacity will be utilized first.

We also note that the number of itineraries used to move freight from origin to destination is relatively constant. This leads us to believe that the solution proposed by NETPLAN is quite stable. This assumption is reinforced when looking at the relatively small number of modified

Table 4.

Results obtained when varying demand by ±20% with CNX data

Demand variation	$d_m = 0{,}80\bar{d}_m$	$d_m = \bar{d}_m$	$d_m = 1{,}20\bar{d}_m$
transportation and handling costs ($1,000)	435 (84%)	519 (100%)	607 (117%)
total service frequencies	936 (86%)	1,094 (100%)	1,273 (116%)
itineraries used	1,039	985	1,007
number of modified itineraries for the most important traffic classes	31 (11%)	--	20 (7%)

Table 5.

Results obtained when varying demand by ±20% with data provided by Transport Brazeau Inc.

Demand variation	$d_m = 0{,}80\bar{d}_m$	$d_m = \bar{d}_m$	$d_m = 1{,}20\bar{d}_m$
transportation and handling costs ($1,000)	310 (92%)	337 (100%)	371 (110%)
total service frequencies	645 (91%)	712 (100%)	811 (114%)
itineraries used	453	454	453
number of modified itineraries for the most important traffic classes	16 (15%)	--	9 (9%)

itineraries used by the most important traffic classes, i.e. those representing the vast majority of demand. It is thus possible to study those modifications in order to determine contingency plans (itineraries) that can be implemented when required.

One such analysis is illustrated in table 6 where demand for a specific traffic class (Montreal-Vancouver) is modified, while maintaining the demand for all other traffic classes constant, using data from Transport Brazeau Inc. Results indicate that freight moving from Montreal to Vancouver will first be directed to Calgary for consolidation when the demand level is less than 76,800 pounds per week. As volume increases above

that level, a new itinerary is suggested by NETPLAN, as freight is then moved directly from Montreal to Vancouver without rehandling in Calgary.

Many more analyses were performed with NETPLAN. They are reported in Roy (1984) for the CNX experiment and in Tassoni (1987) for the set of data provided by Transport Brazeau Inc. These tests and analyses have confirmed the good behavior of NETPLAN and the quality of its solutions.

Table 6.

Demand variations for a given traffic class (Montreal-Vancouver) using data provided by Transport Brazeau Inc.

demand (in 100 pounds)	itinerary proposed by NETPLAN	frequency of service MTL-VAN
96 (D/4)	MTL → CGY → VAN	0
384 (D)	MTL → CGY → VAN	0
576 (3D/2)	MTL → CGY → VAN	0
768 (2D)	MTL → VAN	3
1,152 (3D)	MTL → VAN	4
1,920 (5D)	MTL → VAN	5

Note: MTL: Montreal
VAN: Vancouver
CGY: Calgary

7. CONCLUDING REMARKS

The two experimental studies summarized in this paper give an indication of the huge potential of NETPLAN as a tactical planning tool for LTL carriers. In particular, it can help produce a transportation plan which will insure that next period's demands are satisfied at the right level of service with minimum transportation and freight handling costs. The planner may then interact with the system to choose among several different solutions with basically the same objective value and to manipulate the selected one until the operating policies respect all the company's unwritten or unprogrammable rules and objectives.

NETPLAN can also be used to assist motor-carriers in their strategic decision-making process by evaluating the consequences of various scenarios involving the terminal network (opening of new terminals or closing of existing ones, changes in size of terminals, etc.). One such application is the Canada Post Corporation's network reconfiguration study which is presently under way. The model has been adapted to deal with the transportation of several types of products (first class mail, parcels, etc.) in a service network composed of 49 terminals and 8 transportation modes (from planes to trucks) all across Canada. It has been installed on an IBM PC/AT microcomputer, along with an operating interface that allows the user to interactively communicate with the system to prepare scenarios, to access, explore and modify the data bank, to display and analyse data and results. Preliminary results suggest that NETPLAN works quite well.

Further research is needed in order to properly adjust NETPLAN to actual motor-carrier operations such as the use of a single tractor to pull two or even three trailers on some highways, the use of baseloads and other loading practices that increase equipment utilization, etc. These new developments are presently under study. In particular, a new version of NETPLAN which considers explicitly the use of baseloads will soon be tested on actual data provided by Transport Brazeau Inc.

To be really effective in a working environment, NETPLAN will be part of a comprehensive planning tool combining a data bank together with procedures to access and analyse it, procedures for post-optimal analysis and an interactive-graphics capability to display and help study data and results. A research group at the Centre de recherche sur les transports (Université de Montréal) is currently developing and experimenting these types of procedures – see in particular the work of Crainic and Mondou (1986) on the graphic representation of data.

Finally, research is under way in order to propose solutions to problems closely related to the tactical planning level, such as the crew scheduling (planning of bids for drivers) and empty vehicle return problems. In these two cases, the transportation plan produced by NETPLAN will act as an input to the solution process of both problems.

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